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Basic Research in Human Factors

Harold Van Cott and Elizabeth Neilsen

Committee on Human Factors, National Research Council

for

Contracting Officer's Representative
Michael Drillings

Basic Research
Michael Kaplan, Director

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This report outlines the purpose, membership, and recent activities of the Committee on Human Factors. It summarizes current studies in the areas of human performance models, multicolored displays, distributed decision making, expert systems, and aging. The report also discusses reports from 1984 through 1988 that represent the areas listed above.

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BASIC RESEARCH IN HUMAN FACTORS
SUMMARY

The Committee on Human Factors was established in 1980 in the Commission on Behavioral and Social Sciences and Education by the National Research Council at the request of a consortium of five major government agencies. The purposes of the committee are to provide guidance and recommendations for the support of basic research relevant to the discipline of human factors by these government organizations, to serve as a mechanism for interdisciplinary communication, to encourage the participation of scientists in conducting basic investigations relevant to major theoretical and methodological issues, and to respond to the needs of sponsors for advice on specific issues relating to their research programs.

During 1988, more than 80 scientists, representing a wide variety of disciplines, contributed their expertise on a voluntary basis to the various activities of the committee's core program. The committee continued to oversee work on the reports of studies on human performance modeling, aging, multicolored displays, expert systems, and distributed decision making. Work on draft reports of the workshops on expert systems and distributed decision making is in progress. Work is also underway on a letter report to the Office of Naval Research on fundamental issues in human-computer interaction. It is expected that these draft reports will be ready to enter the review process late in 1989. The final draft reports of the working group on human performance modeling and the workshops on multicolored displays and aging are in Academy review and it is expected

that these reports will be published in mid-1989. The committee published the report of a study on Ergonomic Models of Anthropometry, Human Biomechanics, and Operator-Equipment Interfaces.

An effort was undertaken to increase the dissemination of the committee's reports. Summaries and/or listings of committee reports available from the National Academy Press were published in the Human Factors Society Bulletin and other relevant professional newsletters in 1988, and a general distribution mailing list for committee reports was developend. An additional effort is underway to publicize committee reports through the newsletters of scientific and technical associations and societies, and to investigate the potential interest of commercial scientific and technical publishers in publishing some or all of the committee's reports.

The level of sponsorship of the committee increased substantially during 1988. From the original three agency sponsors, a total of nine sponsoring agencies have now taken an active interest in supporting and funding the work of the committee.

INTRODUCTION

The core program of the Committee on Human Factors (COHF), a standing committee in the Commission on Behavioral and Social Sciences and Education (CBASSE) of the National Research Council since October 1980, is sponsored by the Office of Naval Research (ONR), the Air Force Office of Scientific Research (AFOSR), the Army Research Institute (ARI), the

National Aeronautics and Space Administration (NASA), the National Science Science Foundation (NSF), the Air Force Armstrong Aerospace Medical Research Laboratory (AAMRL), the Army Advanced Systems Research Office (AASRO), the Army Human Engineering Laboratory (HEL), and the Nuclear Regulatory Commission (NRC).

OBJECTIVES

The mandate of the Committee on Human Factors is to:

- advise its sponsors regarding the most important basic research needs in human factors engineering and provide guidance on methods for investigating such problems;

- explore in depth the state of knowledge in selected areas judged to be of particular importance as a basis for the development of detailed research agendas;

- provide a mechanism for encouraging contact and communication among both basic and applied researchers in the field in the United States and abroad;

- interest outstanding young and senior scientists outside the field of human factors in conducting basic research relevant to major theoretical and methodological issues;

- be responsive to sponsors' requests for advice on specific problems or issues relating to their human factors research programs.

MEMBERSHIP

Members of the committee and its study groups are selected on the basis of their expertise, as demonstrated by their contributions to the advancement of science in their areas of specialization. They constitute a broad, balanced representation of the human factors and related disciplines. In addition to human factors specialists, the committee and its subgroups include experts in the fields of experimental psychology, biomechanics, mathematical psychology, cognitive and information sciences, sociology, business administration, organizational and industrial psychology, and engineering. Each of these experts serves on the committee or its subgroups without reimbursement other than for travel expenses related to committee activities. Committee members are listed in Appendix A and study participants are identified in Appendix B.

ACTIVITIES DURING THE PAST YEAR

MEETINGS

The Committee on Human Factors met in January, May and October of 1988.

Topics discussed at the January meeting included the selection of new core projects, the status of committee membership, discussion of a meeting on neural/cognitive science, and the formation of planning and nominations subcommittees. In addition, the progress of on-going studies was

reviewed. At its May meeting, the committee devoted its efforts to a detailed review of current studies and also finalized an agenda of topics for study in FY 1989. The progress of efforts to increase distribution of committee reports was also reviewed. At the October meeting, the committee reviewed the core proposal covering the three-year period from 1 February, 1989 to 31 January, 1992. In addition, committee subgroups met to establish working plans for new projects on the augmentation of human intellectual functioning, organizational effectiveness, and human error, and to discuss proposed panel members for these new studies.

REPORTS

Published Reports

The final report of the workshop on integrated ergonomic modeling was published in FY 1988. Abstracts of currently available reports appear in Appendix C.

Reports in Review

Reports of studies on human performance modeling, and applications of multicolored displays are being revised subsequent to review, and are scheduled for completion during FY 1989. Reports of a study on aging and a letter report on fundamental issues in human-computer interaction have entered the Academy review process, and it is expected they will be published in FY 1989.

Working Group on Human Performance Modeling. This working group has identified research needed for the description and prediction of human

performance in systems using theoretical models. Its report examines existing modeling efforts and recommends studies to enhance the ability to represent integrative human performance analytically.

Workshop on Multicolored Displays. This study involves research issues related to the use of multicolored displays. The workshop explored the problems inherent in colored displays and their suitability for particular systems applications and the report develops a research agenda for the use of color in transilluminated and reflectance displays.

Workshop on Human Factors Issues For Aging Populations. The report of this workshop includes an analysis of tasks required of aging persons related to the home, workplace, community, and transportation. These task requirements are considered with respect to major functional capabilities, and areas where research is needed are delineated.

Letter Report on Fundamental Issues in Human-Computer Interaction

The report addresses the nature and opportunity for basic research in human-computer interaction, discusses situated cognition and HCI, analysis of natural cognitive performance, definitions and tests for basic HCI research, and the relation of basic to applied and exploratory research in human-computer interaction.

Reports in Preparation

Preliminary reports on expert systems and distributed decision making are in preparation.

Workshop on Distributed Decision Making. This study addressed the problems involved in making command decisions when individuals and sources of information are located at different sites. The report will recommend research needed to implement effective decision making in organizational structures where information may be incomplete.

Workshop on Expert Systems. The report will present an analysis of the methodology and research issues involved in the development of expert systems, including knowledge acquisition, function allocation, tutorial application and human-computer interface.

SUMMARY OF CURRENT STUDIES

The following summaries detail reports currently in the Academy review process, as well as those reports being prepared for review.

Human Performance Models (Report in Review):

Many models have been constructed to represent elemental human performance. Such models are useful for predictive measurement, as design tools, or for promoting effective communication between behavioral specialist and designer. However, much research remains to be done before generic models can be produced which are easily adapted to specific task contexts, and which provide design and development information at a useful level of abstraction for systems of varying complexity.

Models serve a number of purposes in human factors engineering. They reduce development time by providing predictions which limit the design domain that must be explored empirically; they are used as design tools by system developers; they provide a normative base against which to evaluate particular human performance; and they promote useful communication between the design engineer and the behavioral specialist.

Progress over the past fifteen years has led to the present ability to represent analytically, either in mathematical or computer form, selected aspects of integrated human performance. Optimal control models (OCM) of manual control have proved useful in reducing the amount of experimentation and simulation required to develop piloted vehicle systems. The SAINT simulation language has been specifically designed to represent human task performance. The Human Operator Simulator (HOS) has made it possible to integrate elementary models of human performance into larger task-related simulation.

However, the state of model development for large-scale multiperson systems remains crude. For many human activities, behavior is understood at a level which admits only simple taxonomies or verbal-analytic models. At the opposite end of the spectrum, if a task is sufficiently defined, it is always possible to build a computer program which will produce the same output as a specific task execution sequence performed by a particular individual. Such a program is only of interest, however, if it can be extrapolated to predict individual performance when system variables are changed. Such generalization has been achieved only in limited task contexts. In terms of the range of behavior and task situations which can

be described with useful generality, there is a continuing requirement to narrow the gap between verbal analytic representations and predictive models. In addition to the need for generation of such models, there are also methodological issues to consider. For example, what is the proper modeling framework? What methods and procedures should be used for validation? What are the acceptable degrees of freedom for the parameters of such a model?

The working group has reviewed current studies on macro models and has identified research needed for the description and prediction of human performance. Its report, which will recommend research studies to enhance the ability to represent integrative human performance analytically as a guide to system design, is scheduled for publication in FY 1989.

Multicolored Displays (Report in Review):

Over the past decade, with the growing sophistication of microelectronic processing and digital computation, there has been a concurrent increase in the use of color displays for a variety of systems and applications. Multicolored displays are increasingly used in a variety of civilian and military systems including aircraft, ships, and command, control and communication centers. These displays have a number of advantages relative to monochrome or black and white displays. Color provides an additional dimension for coding, spatially confused graphical or text information can be grouped or segregated, ranges of quantitative values can be differentiated easily and critical features can be highlighted. Furthermore, the addition of color to otherwise achromatic displays

provides interest, aesthetic appeal, and some measure of perceived realism. The addition of color also appears to provide the user with greater sensitivity to the subtleties of display content.

However, multicolored displays are not inherently necessary or useful for all applications. It is argued that color has been indiscriminately added for the sake of technology and not for the benefit of the user. The inappropriate addition of color to otherwise achromatic or monochromatic displays may degrade the utility of the display, leading to reduced user performance. There are other problems associated with these displays which can offset their advantages. Relative to monochrome or black and white display, a multicolored display is more expensive, maintenance requirements are greater, there is some sacrifice of display resolution, and an increased probability of certain kinds of human errors.

There is a need for guidelines to assess whether multicolored displays are warranted in particular systems. There is also a need to determine how multicolored displays can be employed most advantageously and to define the characteristics of these displays which must be specified to ensure that they meet functional requirements.

At a two-day workshop, the current uses of color in visual displays were categorized along three dimensions: display content, purpose of color in the display, and display dynamics. Representative examples of display designs relative to these categories were discussed, along with applicable questions relating to color selection, design of color systems, and visual implications of display design. In addition, representative research

issues and findings that are central to the selection and use of color in various types of displays were addressed. A report containing research recommendations pertinent to the general and specific uses of multicolored displays is in preparation, and is scheduled for publication in FY 1989.

Aging (Report in Review):

With the median age of the general population increasing, understanding the ramifications of the aging process has become a critical issue. In the course of aging, changes occur in the levels of physiological and psychological functioning. Functional capabilities will determine to a large extent how well older persons can perform in the home, workplace and community. Although some work has been done to encourage alterations in these environments to accommodate the aging individual, quantitative data are lacking to describe the effects of functional changes on the activities of an aging population.

To address this issue, a study was initiated to provide an overview of the human factors aspects of the aging population in the context of daily living in the home and community and in the work force. The goals of the study were to identify and analyze tasks typically encountered in transportation, home, workplace, leisure, and safety/security activities; compare the demands that these tasks make on functional capabilities; develop a methodology for comparing the functional capabilities with the functional demands of the tasks; and recommend research needed to provide additional human factors data on the aging population.

Five categories of tasks and activities were identified that are of primary concern. For the majority of older people, access to transportation is fundamental for remaining independent, maintaining a social network, and participating in activities outside the home. Maintaining independence within the home environment is also an integral factor in the psychological and physical well being of the aging individual. In addition, many older people are extending their working years, and modifications to the work environment, redesign of tasks, and retraining programs may prove essential to retain the valuable pool of knowledge and skills represented by the older worker. For an enhanced, balanced quality of life, older individuals also need to remain active and involved in a variety of leisure activities, but functional deficits can limit the extent and nature of such activities. Improved understanding of these deficits can result in human factors design of facilities and equipment for use by the aging person. Furthermore, because many older people have concerns about their personal safety and have feelings of vulnerability, a major component of their psychological well being is the sense of being safe and secure in the home, community and the workplace.

These task environments were studied in the context of functional capabilities. Changes in sensory/perceptual, physical/physiological, and cognitive/psychomotor functioning are an integral part of the aging process, and these changes represent limitations on the independent functioning of the older population. For example, decrements in audition can limit communication, while declining visual functioning can affect the ability to drive a vehicle or to perform work related tasks. Certain systemic changes can limit independent functioning due to decreases in

strength, agility, and endurance. Difficulties in learning and retrieving information can have a particular impact on work performance. In addition, more rigid attitudes, and reduced motivation to change may affect each of the other functional capabilities.

Applying system and task analysis methodology to the jobs and activities of the aging, and comparing the capabilities of older persons to task demands can help provide an empirical rationale for research required to maintain or enhance the functional capabilities of the aging. With this goal in mind, a study panel was convened to identify and recommend basic human factors research needed to effectively use the talent resident in the aging work force, and to improve the quality of life of older persons in the home and in the community. It is expected that the report of this study, which is co-funded by the National Institute on Aging, will be published in FY 1989.

Fundamental Issues in Human-Computer Interaction (Letter Report in Review):

The topic of human-computer interaction provides important opportunities for basic research in cognitive psychology and cognitive science. HCI involves nearly the entire range of human and machine intelligent activities, engages a wide variety of fundamental research questions, and provides an excellent context for their exploration. Moreover, unlike many basic research issues in cognition, those raised and answered in the context of HCI are likely to have direct and testable consequences for application, providing a kind of evaluation for completeness of understanding not often available in cognitive research.

Although the interaction of humans with the computer is not inherently a domain of basic natural science research, in the broader view, both can be seen as information processing systems capable of independent intelligent behavior and of interaction with other similar intelligent agents. Understanding such interactions will require several kinds of research, from theoretical/mathematical modeling and analysis of interacting systems to parametric studies of human cognitive task performance.

However, there are a host of more narrowly focused fundamental cognitive problems that arise in, and/or are best studied in the context of HCI. There are two major perspectives from which such problems can be identified. One is the view that many cognitive processes are intimately context-dependent. HCI offers un unexcelled laboratory for the study of such "situated cognition" because it allows the intentional construction and instrumented observation of interactive cognitive tasks at the level of complexity required of modern humans. Illustrative examples of potential research issues in cognition situated in HCI are problem solving; graphical and pictorial perception; memory and information retrieval; instruction and tutoring; and interpersonal communications.

The second source of fundamental research issues in HCI derives from the observation and analysis of the limits and characteristics of human performance when using computer systems to do cognitive work. Such analysis will almost certainly disclose problems in the acquisition or exercise of the required skills that would be worthy of further research. Examples of such problems include individual differences; information representation and organization; programming; and reading.

The report concludes that definitions and tests can be derived to identify appropriate basic HCI research, and addresses the relationship between basic, applied, and exploratory research in human-computer interaction. It is expected that this letter report will be published in FY 1989.

Distributed Decision Making (Report in Preparation):

For the past 20-30 years, behavioral decision theory has been used to develop aids which can help experienced decision makers select among alternatives by mental processes that analyze the salient features of a situation, consider the various ranges of interpretations and actions, evaluate the consequences of each alternative, and select appropriate responses. The most promising approaches appear to be based on a mixture of prescriptive and descriptive research. The former asks how people should make decisions, while the latter asks how they actually do make them. In combination, these two research approaches attempt to build from people's decision making strengths, while compensating for their weaknesses. The underlying premise is that significant decisions should seldom be entrusted entirely either to unaided intuition or to automated procedures. Finding the optimum division of labor requires an integrated program of theoretical and empirical research.

Modern command-and-control systems represent a special case of a more general phenomenon, in which the information and authority for decision making are distributed over several individuals or groups. Distributed decision making systems can be found in such diverse settings as military organizations, voluntary organizations, multinational corporations,

diplomatic corps, government agencies, and couples managing a household. Viewing any distributed decision making system in this broader context helps to clarify its special properties.

A general task analysis of distributed decision making systems is developed by detailing the performance issues that accrue with each level of complication, as one goes from the simplest situation (an individual intuitively pondering a static situation with complete information) to the most complex (heterogeneous, multiperson systems facing dynamic, uncertain and hostile environments which threaten the communication links and personnel in their system). Drawing from the experience of different systems and from research in areas such as behavioral decision theory, psychology, cognitive science, sociology, and organizational development, the analysis suggests both problems and possible solutions. It also derives some general conclusions regarding the design and management of such systems, as well as the asymptomatic limits to their performance and the implications of those limits for an organization and overall strategy.

Many civilian, military, and space systems consist of physically separated components which are linked through telecommunications networks and act semiautonomously, but cooperatively toward common goals. To enhance flexibility and to take best advantage of local information, there is an increasing trend to distribute decision making authority among system components. Of critical importance is understanding the fundamental requirements which must be met to enable individuals within different organizational components to make decisions effectively and cooperatively

with only partial sharing or availability of information. Design of system architecture, decision making protocols, and information support networks will all require knowledge about human decision processes in distributed systems.

A report, based on position papers submitted by workshop participants and on the proceedings of the workshop, is in progress. This report, which will delineate recommendations for fundamental research studies in distributed decision making, is scheduled for publication in FY 1989.

Expert Systems (Report in Preparation):

Expert systems, a branch of artificial intelligence, include a core of specialized knowledge and a prescriptive or descriptive method for acquiring, utilizing, and interpreting that knowledge. There is considerable interest in understanding the structure of expert systems, how to build them, and what they tell us about the nature of expertise. Research is needed to discover methods for learning what the expert's core of knowledge is, what heuristics or rules govern the utilization of this knowledge to solve particular classes of problems, and how best to convey the knowledge to a non-expert user of the system.

The Research Briefing Panel on Cognitive Science and Artificial Intelligence of the National Academy of Sciences has cited expert systems research as an important topic. Related research topics involve exploring the nature of intelligence and its development from primitive cognitive functions; solving complex problems by developing computer systems which

have intellectual, perceptual, and learning abilities; using computers' increasing speeds of data processing and extended memory; and combining an understanding of the way humans learn and perform cognitive tasks with intelligent systems. The report identified as a central research issue a method to provide for increased expertise by integrating vast bodies of knowledge and extensive search processes into a single system.

One of the major human factors issues in the domain of expert systems is how to find out what the expert knows, both the knowledge base itself and the problem solving processes that relate to that knowledge. What rules do experts use to understand and retrieve appropriate subsets of their knowledge base? Should they be asked to describe what they know and the cognitive processes they use? Should they be observed, and their activities recorded, in settings where they apply their knowledge? Are new and quite different approaches required to gain access to the expert's knowledge and problem solving techniques?

A second critical human factors issue is how best to present the resident information to the user of an expert system. Because novices frequently do not think in the same terms as an expert, attention must be given to translations or explanations of the information. Furthermore, while in some cases a simple answer to a problem is sought from the system, other situations may demand a tutorial. Determining how to pass expertise on to the nonexpert is central to human factors research on expert systems. As knowledge-based programming tools become more readily available and advancements in computer data processing speeds and capacities make large systems more reliable, efforts to develop expert systems are likely to

intensify. A two-day workshop focused on function allocation, knowledge acquisition, tutorial, and human-machine interface aspects of expert systems. The report of the proceedings of this workshop is in progress and is scheduled for publication in early FY 1990.

REPORTS

Prior reports prepared by the Committee on Human Factors:
(These reports are summarized in Appendix C)

Research Needs in Human Factors (1983)
Research Needs on the Interactions between Information Systems and Their Users (1984)
Research Issues in Simulator Sickness (1984)
Research and Modeling of Supervisory Control Behavior (1984)
Methods for Designing Software to Fit Human Needs and Capabilities (1985)
Human Factors Aspects of Simulation (1985)
Recommendations for Content Revision and Alternate Delivery Modes for the Human Engineering Guide to Equipment (a letter report) (1985)
Mental Models in Human-Computer Interaction (1987)
Ergonomic Models of Anthropometry, Human Biomechanics, and Operator-Equipment Interfaces (1988)

Reports scheduled for publication in 1989:
(These studies are summarized in the earlier text)

Human Performance Modeling
Research Needs in Multicolored Displays
Theoretical Issues in Distributed Decision Making
Research Issues for an Aging Population
Fundamental Issues in Human-Computer Interaction (Letter Report)

APPENDIX A
COMMITTEE ON HUMAN FACTORS
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APPENDIX B

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APPENDIX C

REPORTS - 1984-1988

Research Needs on the Interaction Between Information Systems and Their Users: Report of a Workshop (1984):

Regardless of the efficiency of the internal mechanisms of an information system, its overall effectiveness depends heavily on its compatibility with a human user. The purpose of this study was to (1) define the unique characteristics of information systems and estimate trends of future technological development that are likely to affect their character; (2) identify the human cognitive characteristics most importantly involved in user-information system interaction and define the significant behavioral and cognitive science issues; (3) explicate the impact of instrumentation and methodological considerations on experimentation and issue development; and (4) formulate recommendations and justifications for fundamental experimental research most necessary to improve the effectiveness of information systems.

The report of this study suggests that the interaction between users and information systems must be a major focus of research aimed at improving total system performance. Knowledge of the capabilities and limitations of humans as processors and users of information must be extended, the abilities, needs, and preferences of potential users must be better understood, and the social and economic implications of this

technology must be considered if the full benefits of engineering advances in information technology are to be realized.

More specifically, the report indicates that there is a paucity of theory-based research on user/information system interaction. To provide a basis for cumulating the results of research and making them broadly applicable to the design and use of these systems, more attention must be paid to the development of a theoretical foundation.

In addition, more needs to be understood about the acquisition and use of information. Research is needed on the distinction between information and its representation to improve assimilation and transfer, and on the methods people use to find information. Research is also needed on effective means of filtering and evaluating information, and on understanding how people organize and manage information spontaneously in order to develop techniques which will help them do so more effectively.

Attitudes towards and accommodation to rapidly advancing information technology need to be better understood. In particular, human interaction with this technology in the workplace is a largely unexplored area which demands attention.

The report also suggests that research is needed to better understand the cognitive effects of programming, to increase the rate of information exchange between people and information systems, to develop user skills, and to assess the impact of technology on jobs and job skills.

Research Issues in Simulator Sickness: Proceedings of a Workshop (1984):

The adverse training consequences of simulator sickness and the uncertainty about its etiology, contributing simulator characteristics and possible countermeasures clearly indicated the need to investigate this problem. The principal objectives of this study were to (1) assess the existing data on the frequency, severity and circumstances of occurrence of simulator sickness; (2) identify the simulator design characteristics and training methods which may contribute to the occurrence of simulator sickness; (3) assess the efficacy of currently practiced countermeasures; (4) recommend alternative or additional remedial steps which may be taken; and (5) recommend research and other actions to achieve a long-term solution to the problem of simulator sickness.

The report of this study identifies five areas where additional research is needed: problem definition, theory/model development, methodology, determination of causes and processes, and validation of candidate countermeasures.

The magnitude and consequences of simulator sickness must be determined in order to make reasonable recommendations about solutions. It is recommended that field studies of simulator sickness be conducted in order to define the nature and extent of the problem.

The report suggests that quantification of sensory conflict is a major research goal for the study of simulator sickness, and that a mathematical model of the conflicts that cause the problem will help make

the theory of sensory conflict testable and will guide the necessary research.

The methodological approach should be to determine what appear to be the most significant variables and to investigate these initially. The reliability of the dependent measures of simulator sickness need to be studied, and reliable criteria for effective analysis of the problem need to be developed. In addition, physiological indices of motion sickness should be investigated.

Determination of causes and processes is recommended as an essential area for research. Analyses of tasks, head movement, visual display and motion-base variables relative to the incidence of simulator sickness must be investigated. More research is also needed to determine the contribution to simulator sickness of such factors as field-of-view size, vection, the phase and gain relationship of various sensory processes, and certain oculomotor variables. In addition, to understand the simulator sickness phenomenon, more needs to be known about the underlying neurological mechanisms and about the role of adaptation.

Evaluation of candidate countermeasures should also be a central part of on-going research on simulator sickness. Incremental exposure regimens, certain hand-eye coordination games, and medications used for motion sickness might be effective in the prevention or control of simulator sickness. In addition, there seems a reasonable hope that degrading the update rate of moving stimuli in the simulator display might

be sufficient to support training while eliminating simulator sickness. These, and other potential countermeasures require further investigation.

Research and Modeling of Supervisory Control Behavior: Report of a Workshop (1984):

In many modern complex systems, the role of the human operator has changed from directing manual control to that of supervising the functions of automated equipment, which in turn controls a vehicle or process through its own sensors and effectors. The task of the human in these systems requires more monitoring and decision responsibility and reduced direct psychomotor control. Specific issues of research strategies to study supervisory control behavior, approaches to modeling this behavior, and means for real-world validation of research and modeling results were addressed over the course of this study, and the resulting report includes recommendations for modeling approaches and research needed to understand the role of the human in these systems in order to improve system design and operation.

The conclusions and research recommendations of this report draw on three major themes: characteristics and analysis of supervisory control systems, selection of research methods, and improved communications between research investigators and designers of these systems.

The report recommends that research on characteristics of supervisory control should center on levels of control, goal setting and seeking, cycles of control and feedback, and trust in the system.

Methods for analyzing and modeling supervisory control systems are necessary to understand and predict the supervisor's behavior, to provide a common, formal basis for comparisons among systems, to allocate tasks between the supervisor and the computer, and to differentiate the contributions of the system's hardware, software, and personnel resources. Both qualitative and quantitative models should be developed. In addition, an analysis of human error, and how to limit or avoid it, must be considered.

Basic research methods should be reflected to develop behavioral principles as a basis for design and to evaluate design alternatives. This research can be supported by real systems, by high- and low-fidelity simulation, and by context-free laboratory tasks.

Subject and training requirements, individual control styles and behavioral factors are other areas where further investigation is required.

Research is also required to design flexible operator-system interfaces. The operator must have display and control mechanisms to acquire information necessary to make decisions and to exercise control at any level in the system.

Success in transferring behavioral research data, principles, and concepts to designers depends on the extent to which the content, timing, and form of the information are compatible with the design process. However, human factors principles and checklists, lessons learned from

existing systems, and a better understanding of the design process itself are likely to contribute to better communication between researchers and designers.

Methods for Designing Software to Fit Human Needs and Capabilities: Proceedings of the Workshop on Software Human Factors (1985):

Computers are pervasive in civilian and military equipment systems. The compatibility of computer based devices with human users is predominantly dependent upon the characteristics of the software. Researchers interested in the development of principles for the design of user compatible software have a great need for guidance in both research methods and performance measurement techniques. This study includes a description of alternative research methods for designing computer software to fit human needs and capabilities. In addition, the report of this study contains a compilation of human factors approaches useful for research, experimental design, and data collection methods on user performance, which provides design information important to software and computer developers.

The report of this study suggests that research needs fall into three categories: new theories, new representations, and new data collection and analysis methods.

Automation theories would indicate what should be automated and what should be assigned to the human processor. Theories of individual differences would supply information about the different kinds of computer

support required by different user populations, and theories of standardization would suggest which aspects of a system should be standardized for all users.

Many analyses outside the testing of a working system with real end users require some specification of what the system can do, what the user knows about how the system works, and how the user conceives of the task. For this reason, research is needed to develop better representational schemes than those now being used.

Current methods of data collection, measures and analysis are inadequate in several respects, and research is needed to gather more inclusive data in an efficient manner. Research methods considered most likely to produce significant results include representations of the users' understanding of a system, representations of a dialog to convey the design to programmers, more comprehensive task analyses that include memory, perceptual and language considerations as well as timing and error predictions, and hardware advances that allow the collection of logging and metering data for tapping the current use of a system.

Human Factors Aspects of Simulation (1985):

Because of the importance and widespread applications of simulation, and the number of significant behavioral and human factors issues in the design and use of simulators, there was clearly a need to perform a study in this area. The objective of the study was to recommend fundamental research and other courses of action necessary to improve the

understanding and effectiveness of human factors in simulation. During the course of this study, behavioral issues and problems common to many simulators were identified and research was recommended to enhance their effective use. The report of this study includes an overview of simulation including some historical perspective and provides a guide for research and educational practices aimed at improving the future design and use of simulators.

The report of this study draws a number of conclusions. The origin of many of the current problems in simulation is over reliance on the belief that the degree of physical fidelity of a simulator is the principal determinant of its capability to serve its intended purpose. At the same time, the importance of the relationship between how a simulator is used and its effectiveness is not fully appreciated. As a consequence of this imbalance of emphasis, simulators are often not as cost effective as they could be and the contributions that behavioral science and human factors engineering can make to the design and use of simulators are relatively neglected. Many serious issues relevant to simulator effectiveness have persisted because of the failure to recognize that solutions to problems common to a variety of simulator applications must come from a better understanding of the basic behavioral processes involved rather than engineering improvements or fixes.

Although simulators could be improved by better use of existing behavioral and human engineering principles, the potential contribution of these fields is limited by the lack of adequate performance measurement methods and well developed human performance models. Objective and

automated performance measurement systems would greatly facilitate the derivation of detailed quantitative performance information useful for design, training, and research purposes. Moreover, information in this form is necessary for the further development of models of human performance that have a variety of applications relevant to simulation.

This use of models may bring about a solution to the fundamental, overriding problem—the lack of an integrated science and technology of simulation. The design and use of simulators should be based on an integrated multidisciplinary approach that draws on knowledge of engineering, behavioral science, and computer science as well as other fields that bring into balance concerns about physical correspondence between real systems and simulators and how these factors contribute to the effectiveness of simulators.

In response to these conclusions, the report makes three fundamental recommendations for research. Long-range, comprehensive, and forward-looking research plans should be developed to address persistent and emerging simulation problems; long-range stable funding should be provided to encourage the development of academic bases for simulation research; and research to develop near real-time human performance assessment capability for simulation should be given urgent attention.

Assessment of Human Engineering Guide to Equipment Design (Letter Report 1985):

This guide is intended to assist designers, engineers, human factors specialists and others in the understanding and application of human engineering principles. Since its last revision in 1972, a great deal of new, relevant data has been generated and systems have evolved so that they are increasingly automated and software intensive. This study reviewed the scope of the contents of the Guide in light of recent technology. In addition to content, the study assessed the usability of the Guide. The present book format cannot easily meet the needs for each application problem nor accommodate different users' requirements for level of detail. The report of this study recommends implementing the Guide on an interactive computer system which allows flexibility in terms of access strategy and level of detail, suggests additional areas of content consistent with advances in information technology, and recommends the initiation of modern data delivery systems using interactive computer methods.

Mental Models in Human-Computer Interaction (1987):

Users of software systems acquire knowledge about the system and how to use it through experience, training, and imitation. Currently, there is a great deal of debate about exactly what users know about software. This knowledge may include one or more of the following: (1) simple rules that prescribe a sequence of actions that apply under certain conditions;

(2) general methods that fit certain general situations and goals; and (3) "mental models", knowledge of the components of a system, their interconnection, and the processes that change the components, knowledge that forms the basis for users being able to construct reasonable actions, and explanations about why a set of actions is appropriate.

Discovering what users know and how these different forms of knowledge fit together in learning and performance is important. It applies to the problem of designing systems and training programs so that the systems are easy to use and the learning is efficient. Research on the effects of different representations on ultimate performance is mixed. Research on exactly what users know is scattered. Analytical methods and techniques for representing what the user knows are sparse but growing. This report reviews current work and, through this review, identifies several important research needs: (1) detail what kinds of mental representations people have of systems that allow them to behave appropriately in using the software; (2) detail what a mental model would consist of and how a person would use it to decide what action to take next; (3) produce evidence that people have and use mental models; (4) determine the behaviors that would demonstrate a mental model's form and the operations used on the model; (5) explore alternative views of goal-directed representations (e.g., so-called sequence/method representations) and detail the behavior predicted from them; (6) expand the types of mental representations that may exist to include those that may not be mechanistic, such as algebraic and visual systems; (7) determine how people intermix different representations in producing

behavior; (8) explore how knowledge about systems is acquired; (9) determine how individual differences have an impact on learning of and performance on systems; (10) explore the design of training sequences for systems; (11) provide systems designers with tools to help them develop systems that evoke "good" representations in users; (12) expand the task domain of this research to include more complex software.

Ergonomic Models of Anthropometry, Human Biomechanics, and Operator-Equipment Interfaces (1988):

The efficient and safe operation of civilian and military systems requires that tasks, equipment, and the work environment be compatible with the users' capabilities. Since the interactions among these elements of the total system are complex, many researchers and engineers are concerned with the need for ergonomic models that describe the physical characteristics of people and their interaction with the task and equipment in the work environment.

There have been numerous efforts to develop descriptive physical models of the human body. In most instances, the development of anthropometric and biodynamic models has not extended beyond the requirements of a specific application. Such specialized models give little help in predicting or solving general human-technology interaction problems. In addition, many of the existing models cannot be joined to form a more general model or be extended into an ingegrated ergonomic model.

In order to develop a universal ergonomic model, comprehensive and accurate representations are required for such factors as physical size, visual field perception, reach capabilities, loading on muscles and bones, and their responses and strength capabilities.

An integrated ergonomic model could encompass all three of the more primitive models, i.e., providing anthropometric, biomechanical, and interface information for various populations, conditions, and tasks, in their interaction with various technical components. To have the greatest utility, the integated ergonomic model should be capable of generalization and contain adequate refinement of detail to be applicable to other design, research or analytic situations. It must also be user-friendly, and time- and cost-effective.

The report identifies current anthropometric, biomechanical and interface models, and provides examples of their applications, strengths and limitations. It concludes that it is feasible to incorporate various models from these three classes into a general integrated ergonomic model or smaller modules and recommends a program of research for their development, as follows: (1)establish the objectives, procedures, and outline for the development of a general integrated ergonomic model; (2) review and integrate existing anthropometric and biomechanical data bases; (3) develop methods for the analysis of muscular action and joint loads as a result of dynamic actions; (4) develop submodels and modular groups; (5) develop a model for the generic interface between human models and workstation models; (6) develop methods and criteria for the validation of ergonomic models.